IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Patent Application

Applicants:	J. Boer et al.
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Art Unit:	2611
Examiner:	Leila Malek

Title: Signal Quality Estimation in a Wireless Communication System

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DECLARATION OF PRIOR INVENTION UNDER 37 C.F.R. §1.131

We, the undersigned, hereby declare and state as follows:

1. We are named joint inventors of the invention that is the subject of the above-referenced U.S. patent application. We have assigned our respective interests in the patent application to Agere Systems Inc. ("Agere").

2. The invention falling within the scope of the claims in the present application was conceived and reduced to practice at some time prior to March 12, 2001.

3. On or about March 12, 2001, an Agere proprietary document ("Agere Systems ASIC Team Design Note No. WADN129, Rev. C") describing the invention was prepared by inventor Bas Driesen. A copy of this document is attached hereto as Exhibit 1.

4. The document attached hereto as Exhibit 1 demonstrates an actual reduction to practice of the invention in the form of results obtained from a simulation comprising an embodiment of an invention falling within the scope of the claims in the present application. These results are included in this document and labeled as Section 5 and Appendices A and B of this document.

5. All statements made herein of our own knowledge are true, and all statements made on information and belief are believed to be true.

6. We understand that willful false statements and the like are punishable by fine or imprisonment, or both, under 18 U.S.C. §1001, and may jeopardize the validity of the application or any patent issuing thereon.

Date: 21-Nov-2007

Jan Boer

Date: ____________

Bas Driesen

Date: ____________

Ra'anan Gil

Date: 21-Nov-2007

Kai Roland Kriedte

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Date: ____________

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Jan Boer

Date: 22-11-07

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Bas Driesen

Date: ____________

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Ra'anan Gil

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Kai Roland Kriedte

EXHIBIT 1

agere systems	ASIC Team Design Note

No: WADN129 Rev: C	Author: Bas Driesen Date: March 12, 2001
Subject: **OFDM Signal Quality Indicator**	

1. ABSTRACT

This design note describes a preposition for a Signal Quality (SQ) indicator for the OFDM base band processor.

2. CHANGES

- Better description of the performed simulations and the results/figures.
- Signal degradation values recalculated, with respect to the resolution bandwidth.
- Additional simulation performed concerning the relation between the signal degradation and the erroneous packets.
- Included a paragraph about the system related aspects.

3. INTRODUCTION

A Signal Quality (SQ) estimation of the received base band signal can be useful for adapting the rate of the link. This design note presents an algorithm for a SQ indicator and provides simulation results on it.

Rate adaptation takes place inside the transmitter at MAC-level. Until now adapting the rate solely relied on the information acquired through the acknowledgement messages received after each well-transmitted packet, thus an acknowledgement message indicates a correctly received packet. Changing the rate of the link depends on the number of good or bad transmitted/received packages. When two packets in a row are received with errors the rate is switched one rate down, to the transmitter the absence of an acknowledgement message is seen as an error. In practice it appeared that switching the rate down happened to fast and this was found to be especially the case in high-density areas. Due to the higher probability of collision between the different stations, more often an acknowledgement message is missed. At the transmitter side this would imply a receive error. After two such receive errors the transmitter will, according to the algorithm switch down a rate. However errors occurred as a result of a collisions are not dedicated to worsening channel or receive situations. In this case the transmitter should not go down a rate. Increasing the rate is done when 5 packages are received in good order, this need not to be 5 consecutive packages. After receiving 5 packets well the transmitter tries to send once at a rate higher. A positive acknowledgement leads to sticking at this higher rate and the absence of an acknowledgement leads to keeping the lower rate. The same procedure

will then repeat itself. Furthermore it is good to know that the access point will follow the station when switching to a higher rate.

To be able to switch faster, more reliable and in bigger steps between the different rates it is necessary to have a more sophisticated rate-switching algorithm. A way to achieve this is by having a representative signal quality indication at disposal. This signal quality needs to be extracted at the receiver and should be made available at the transmitter, as the transmitter has to set the rate. The receiver can measure the signal quality by processing the incoming messages that can either be payload messages or acknowledgement messages. When assuming quasi-static symmetric channel transfer characteristics and transceiver impairments these messages undergo the same degradation as the actual data sent, and thus will be equal in quality. This will be the starting point of the following outline.

4. ALGORITHM OUTLINE

The idea behind the SQ indicator is measuring the Euclidean distance between the reference constellation points and the received constellation points. The closer the received constellation points are to the reference constellation points the better SQ. For rate independent processing and for the sake of simplicity only the SIGNAL-field of a message is used for the SQ measurement. The SIGNAL-field consists of 24 bits that are rate ½ coded and BPSK modulated, resulting in 48 samples located at +1 or –1 [1].

A first draft implementation of a Signal Quality (SQ) indicator or better a Signal Degradation (SD) indicator in SPW looked like Figure 1. This implementation first scales the incoming samples according to the amplitude estimate of the channel and the power droop to position them around the reference points. The scaled samples are then compared with the reference samples of +1 and –1. The magnitude of the resulting error is then computed and only the path that has the smallest magnitude is forwarded. This leads to 48 magnitude values, summing them results in a number representing the SD.

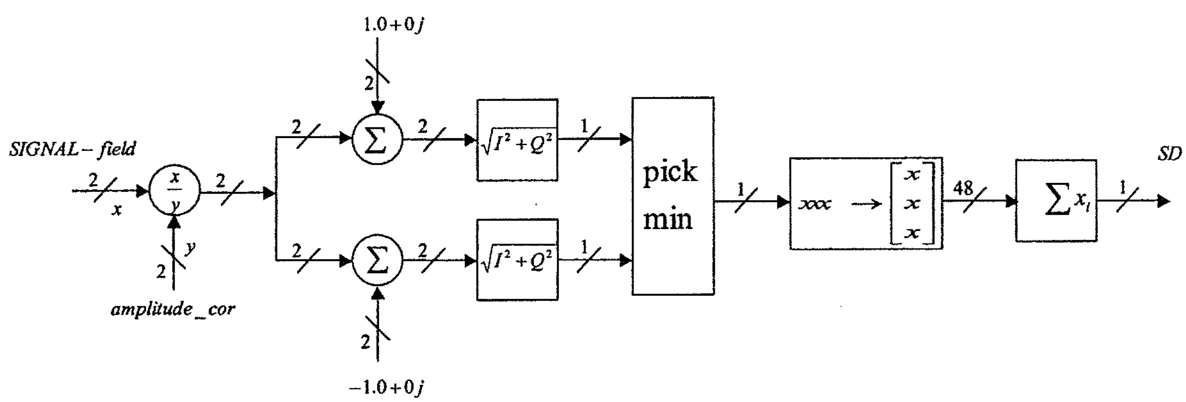


Figure 1: SPW implementation of the Signal Quality indicator

Figure 2 represents a second implementation that is more ASIC friendly. As can be seen this implementation does not use a divide operation and has one path instead of two paths. The summing operation at the end is now implemented as an integrator that

is reset after each SIGNAL-field. A first simplification is mapping all samples to the positive half plane by taking the absolute value of the real part of the incoming samples. This simplification is justified because comparing a sample in the negative half plane with the negative reference point is the same in sense of magnitude as comparing a mirrored version of this sample with the positive reference point. Then instead of comparing the samples with +1 or –1, which needs scaling in front, the incoming samples are compared with the amplitude reference for that specific sub carrier. Further reduction of processing complexity could be achieved when the magnitude is approached by a first order estimate or when instead the power is computed.

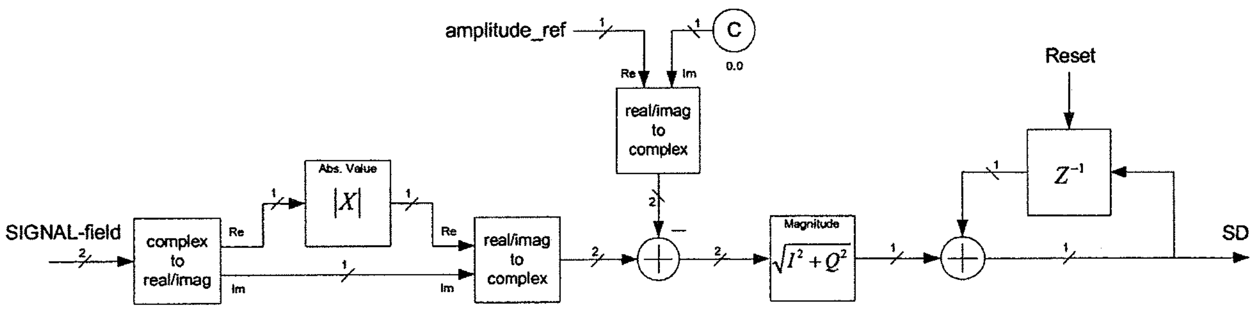


Figure 2: ASIC friendly SPW implementation of the Signal Quality indicator

A different approach would be processing the SIGNAL-field samples as well as the pilot samples. The pilot samples are namely BPSK modulated too and can therefore be processed in the same way as the SIGNAL-field samples. The advantage of this approach would be that the SD is determined using more than only the 48 samples of the SIGNAL-field and therefore maybe resulting in a better estimate of the SD of the packet. However the pilots are always spaced the same in frequency domain, consequently the SD they represent is only related to those specific frequencies, whereas the SD computed using all frequencies can deviate from this, because of frequency selective fading. For this reason a SD indicator based on the pilots is not of use.

5. SIMULATION RESULTS

The simulations performed in this Chapter make use of the first presented SPW implementation scheme. The changes made in the ASIC friendly implementation will lead to somewhat different simulation values, but the conclusions derived in this Chapter will still be valid.

The SD indicator is placed in the level-3 simulation environment at the receiver side behind the *level3mp_pilot_removal_proc_sw2* block. At this point the signal consist of the SIGNAL-field samples and the data samples, the pilot samples are already removed.

The first simulation is done in order to find for specific SNR's and TDS's the corresponding reference/mean SD-values. The simulation is carried out over 200 packets (of which the length is not of interest at this point, so it is chosen as small as possible to speed up the simulations) for a number of SNR's (6, 8, 10, 12, 14, 16, 18,

20, 22, 24, 26, 28, 30) and TDS's (0ns, 50ns, 100ns). The SIGNAL-field of each packet is processed accordingly to the scheme in Figure 1. This will result in 200 different SD-values. The reference/mean SD-values are computed by averaging these 200 SD-values. Figure 3 depicts the reference SD-values/curves for the mentioned range of SNR and TDS values, the corresponding values can be found in Table 2 Appendix A. It can be seen that there is a 2 dB difference in SNR between the 0ns TDS and the 100ns TDS curve for an SD of 5. This means that a system not suffering from TDS can handle about 2 dB more SNR than a system suffering from 100ns TDS, both resulting in the same SD. The difference in SNR between a TDS of 50ns and a TDS of 100ns is about 0.5 dB for an SD of 5, which can be considered as marginal. Furthermore the figure shows that the difference slightly increases for lower SD and slightly decreases for higher SD, which means that at high SD or low SNR the TDS puts less weight to the actual SD, while at low SD or high SNR the TDS puts more weight to the actual SD.

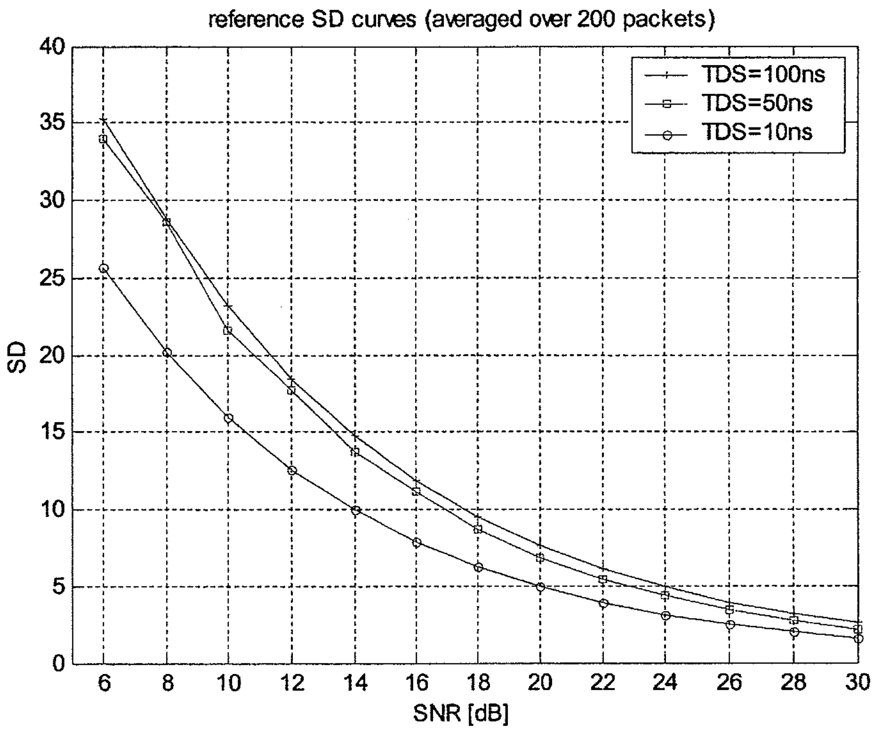


Figure 3: Reference SD curves using 200 packets per SNR and TDS

Ideally the SD of the SIGNAL-field would perfectly match the SD of the total packet. However normally the SIGNAL-field SD cannot represent the SD of the total packet, because the SIGNAL-field SD represents just a small part of the total packet.

A second simulation is done in order to see with what kind of accuracy the SIGNAL-field represents the total packet, which will proof the usefulness of the SQ/SD indicator. The simulation considered is done over 100 60-bytes BPSK modulated packets, which gives 21 payload symbols. When each payload symbol is processed in the same way as the SIGNAL-field symbol, then this results after averaging over the symbols in a SD-value for the total packet. The total length of a packet in samples is `(21 payload symbols + 1 SIGNAL-field symbol) * 48 = 1056 samples`. This number is chosen in such a way that increasing the number does not provide much

more information, this is true because of the fact that a static channel per packet is assumed.

From the simulations it follows that the distribution of the SIGNAL-field SD compared to the total packet SD can be approached by a normal distribution function. A property of the PDF of a normal distribution function is that 95% of its samples lie within μ-2σ and μ+2σ, where μ stands for the mean and σ for the standard deviation. The mean μ equals zero for every SNR and TDS, but the standard deviation σ is different. For a specific SNR and TDS there exists a SD reference value and for that same SNR and TDS there exists a standard deviation σ between the SIGNAL-field SD and the total packet SD. Since the mean μ equals zero the standard deviation σ can be directly mapped to the SD reference values. Figure 4 depicts the SD reference values ± 2σ for simulations with a TDS of 100ns and SNR of 6, 10, 14, 18, 22, 26 and 30 dB. In Table 3 of Appendix A the computed variance σ^2 is given for a TDS of 100ns and certain SNR, from this the standard deviation σ can be derived. The ± 2σ boundaries for a specific reference SD can be linked to the SNR axis. The resolution of the SD is defined as the difference in SNR between the boundaries ± 2σ. From this figure it can be seen that the different SD-distribution regions denoted with different colors overlap, which means that the resolution of the SD in this case is more than 4 dB SNR. Furthermore Figure 4 shows that the resolution for higher SD is worse than the resolution for lower SD, for low SD the resolution approaches the 4 dB SNR.

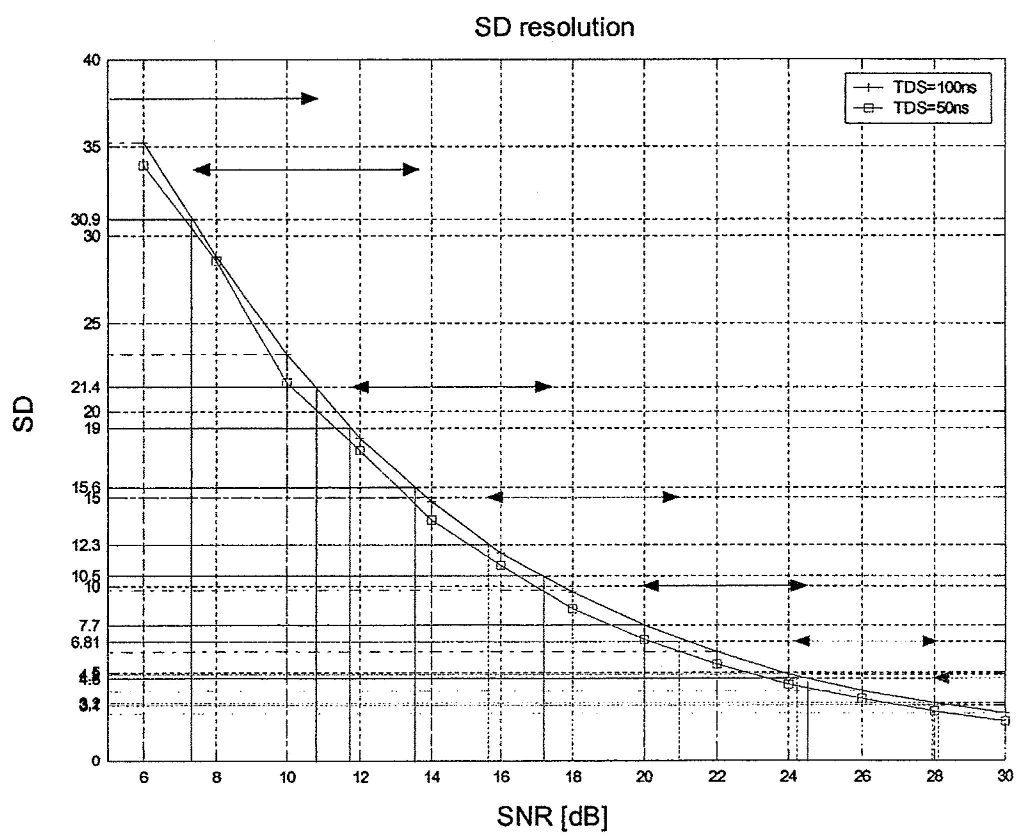


Figure 4: SD deviation, simulated for 100ns TDS and 6, 10, 14, 18, 22, 26, 30 dB SNR

Interpretation of the simulation results requires the SD to be linked to the system performance (PER) curves. Figure 5 depicts the system performance curves at different rates in a fading channel with a TDS of 50 ns. From this figure it shows that for a minimum PER of 5% at a rate of 54 Mb/s the SNR should be greater or equal to 26.5 dB. In Figure 3 an SNR of 26.5 dB for a TDS of 50 ns corresponds to a reference SD of 3.4. Meaning that on the average an SD of 3.4 will give a 5% PER for the rate of 54 Mb/s. Now lets make the assumption that an SD of 3.4 results in 5% PER at 54 Mb/s, which implies that a measured SD of 3.4 or lower is sufficient to achieve at least a 5% PER for that specific rate. However as shown earlier the measured SD will differ from the total packet SD, so a safety margin would be in place here. In the former a resolution bandwidth is determined, which specifies the deviation between the SD of the SIGNAL-field and the total packet. Simulations pointed out that the resolution is worse for higher TDS. The resolution results for the SD at 100 ns TDS can thus be seen as a worst-case scenario for the resolution of lower TDS SD curves. Adding half of the resolution bandwidth to the SNR that leads to a 5% PER for a specific rate results in an SD value of which can be said that it gives at maximum a 5% PER with certainty of 97.5%. Subtracting half of the resolution bandwidth leads to an SD value of which can be said that it gives at minimum a 5% PER with a certainty of 97.5%. As a matter of fact these two derived SD values can be seen as the lower and upper threshold levels for this specific rate. Column 4 and 5 of Table 1 give the lower and upper threshold values for the specified rates. Additionally gives a graphical representation of the lower and upper threshold levels for the different rates.

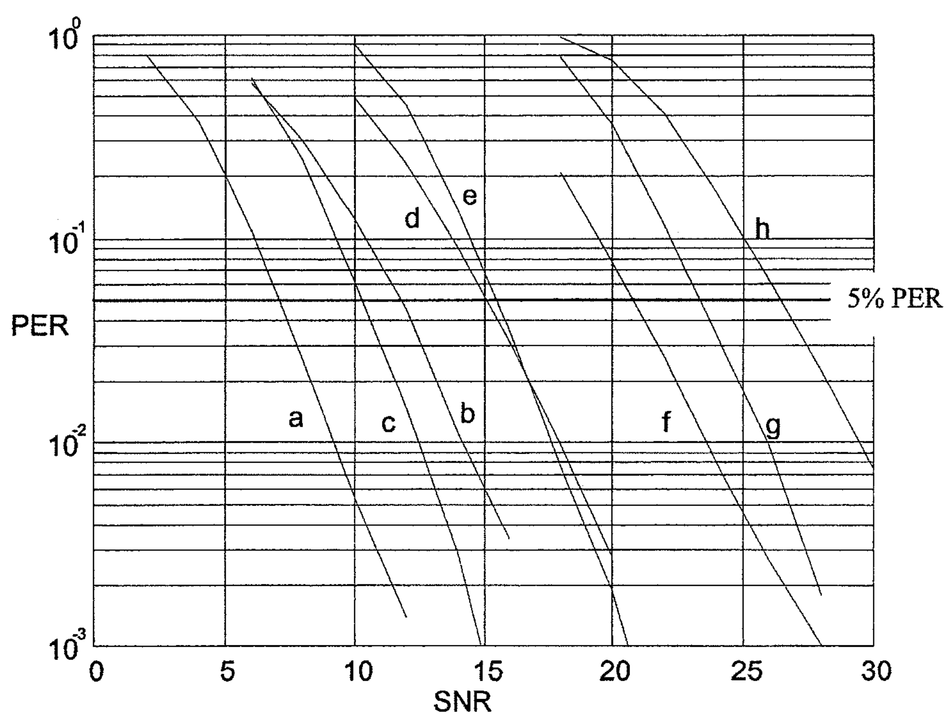


Figure 5: PER versus input SNR for 1000 byte packets in a fading channel with 50 ns delay spread and data rates of (a) 6, (b) 9, (c) 12, (d) 18, (e) 24, (f) 36, (g) 48, and (h) 54 Mbps.

Table 1: Lower and upper threshold SD levels for the different rates for a 50 ns TDS at 5 % PER.

Rates [Mb/s]	SNR at 5% PER [dB]	Resolution [dB]	Low T	Up T
54	26.5	4.0	2.6	4.2
48	24.5	4.5	3.3	5.3
36	20.75	5.0	4.8	8.4
24	15.5	5.5	8.5	16.0
12	10.25	6.0	15.2	30.0
6	7	8.0	19.6	--

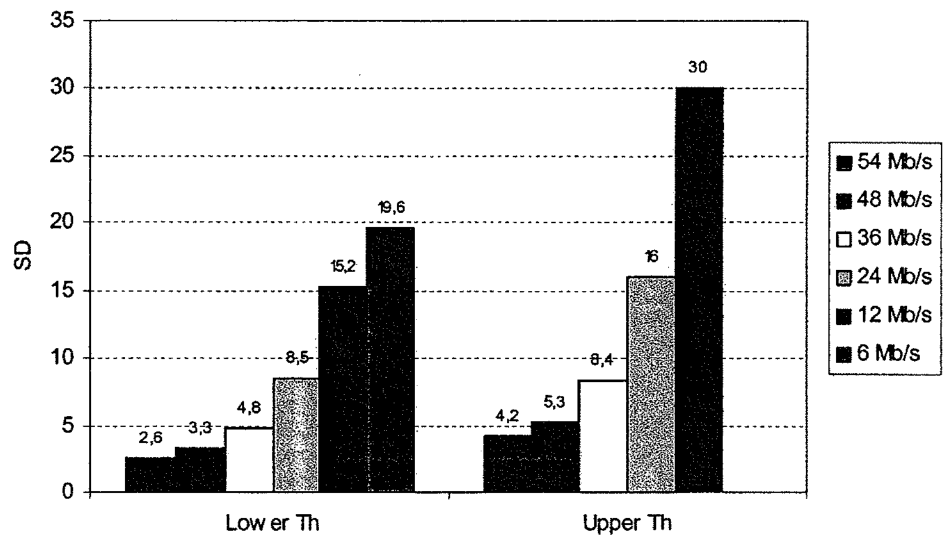


Figure 6: Graphical representation of lower and upper threshold SD levels

Appendix B shows the measured SD values and packet errors for an SNR of 20.75 dB respectively 26.5 dB and a TDS of 50 ns at 36 Mb/s, respectively 54 Mb/s. In these figures the red vertical lines identify SD values corresponding to an error. Furthermore the threshold levels belonging to the specific rate are depicted, the lower threshold level is colored pink and the upper threshold level black. Moreover the green line represents the reference/mean SD value. From these figures the usefulness of the SD indicator comes clearly forward.

A sophisticated rate-switching algorithm could now use the following mechanism. Up switching should be done as soon as the measured SD goes below the lower threshold level of a corresponding rate, however the inverse situation should not lead to a fallback in rate. The fallback mechanism should still rely on the error occurrence, but it might use the past SD information. For example a lower rate could be switched when two errors in a row occur and when a yet to be defined number of past SD values are above the upper threshold level. This method assumes that there does not occur a rapid SD change. So when two errors in a row are received but the past SD values are underneath the upper threshold for that specific rate the transmitter might choose to keep the same rate operable. In such a situation the errors could be attributed to collisions instead of worsening channel conditions. Figure 7 depicts a

state diagram of the proposed rate-switching algorithm. To overcome deadlock the rate should be switched down whenever lets say 5 errors in a row occur.

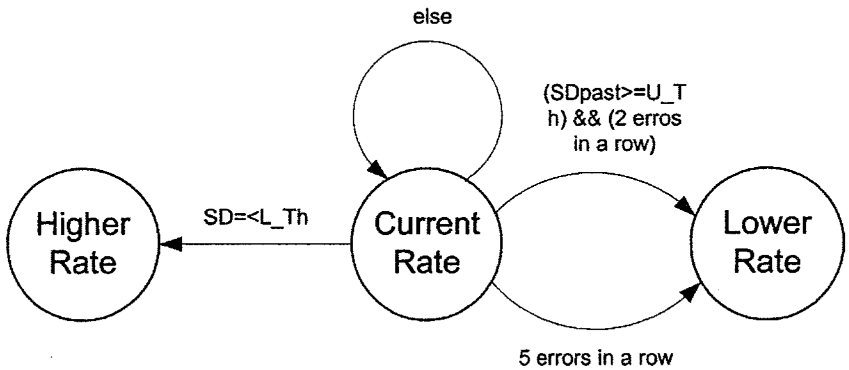


Figure 7: State diagram of possible rate switching algorithm

Simulations where the measured SD value is averaged over more than one packet are also performed. The result is that the lower and upper threshold levels are closer together, which makes it easier to distinct between the different rates at the expense of slower rate switching. However one needs to be careful with averaging over more than one packet, because the time in between packets can be large and in the meanwhile the channel conditions can be changed drastically.

6. CONCLUSIONS

From the simulations it follows that a decision can be made for rate switching on the basis of the measured SD value. A less stringent definition of the SD resolution results in relaxation of threshold levels, but this of course leads to less reliable rate estimation for this specific criterion of 5% PER. A second way of relaxing the threshold levels is to adopt a less stringent criterion, so for example tolerating a PER of 10% instead of 5%.

Implementation of the SQ/SD indicator as in Figure 2 leads to different threshold levels with respect to the threshold levels derived above, because of the fact that the outcome of the implementation differs slightly. However the above analyses still holds.

7. REFERENCES

[1] IEEE Std 802.11a-1999, “High-Speed Physical Layer in the 5 GHz Band”, 16 Sept 1999.

APPENDIX A: SIMULATION RESULTS

Table 2: SD reference values calculated over 200 packets for different TDS and SNR

TDS	SNR	Reference SD values	TDS	SNR	Reference SD values	TDS	SNR	Reference SD values
0	6	25,705	50	6	33,96	100	6	35,23
	8	20,13		8	28,545		8	28,8
	10	15,925		10	21,63		10	23,215
	12	12,6		12	17,7		12	18,38
	14	9,985		14	13,695		14	14,755
	16	7,94		16	11,13		16	11,87
	18	6,29		18	8,665		18	9,55
	20	4,99		20	6,86		20	7,71
	22	3,965		22	5,465		22	6,155
	24	X		24	4,35		24	4,92
	26	2,5		26	3,46		26	3,975
	28	1,99		28	2,75		28	3,23
	30	1,58		30	2,185		30	2,635

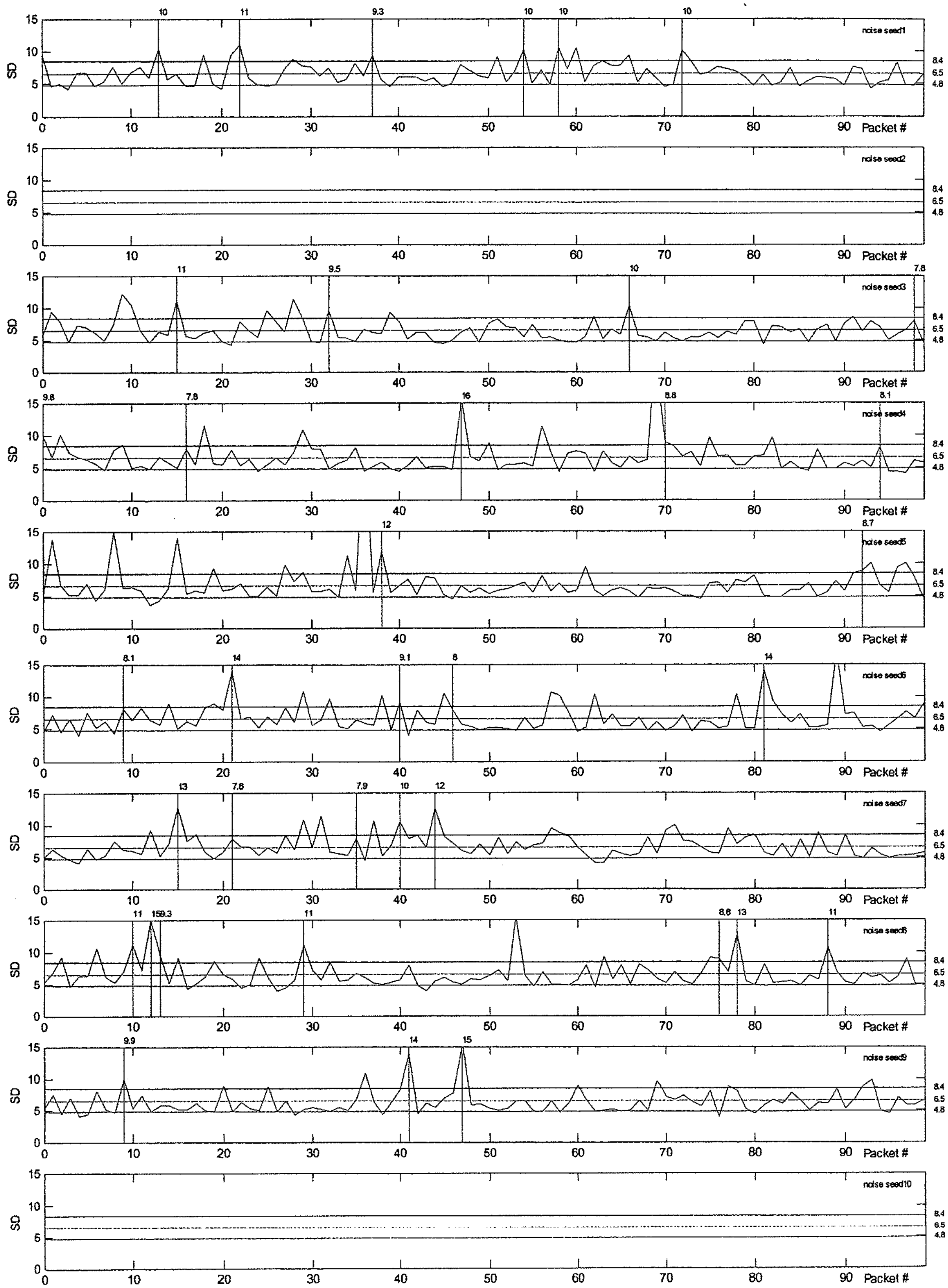
Table 3: Variance between the packet SD and the SIGNAL-field SD for different averaging

SNR	Reference SD (TDS=100ns)	var(SD_packet-SD_SIGNAL)	var(SD_packet_sliding2-SD_SIGNAL_sliding2)	var(SD_packet_sliding4-SD_SIGNAL_sliding4)	var(SD_packet_sliding8-SD_SIGNAL_sliding8)
6	35,23	47,17	22,46	10,35	5,16
10	23,215	14,65	6,38	2,73	1,27
14	14,755	4,47	2,15	1,09	0,63
18	9,55	1,87	0,83	0,38	0,17
22	6,155	0,58	0,246	0,12	0,057
26	3,975	0,2	0,0897	0,0474	0,0237
30	2,635	0,0881	0,04	0,0204	0,011

APPENDIX B:

COMBINED SD AND PACKET ERROR SIMULATIONS

SD and Packet Errors per 1000-bytes Packets for an SNR of 20.75 dB and TDS of 50 ns at 36 Mb/s



SD and Packet Errors per 1000-bytes packets for an SNR of 26.5 dB and TDS of 50 ns at 54 Mb/s